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Division of Plant Pathology

Fusarium Wilt of Peas with Special
Reference to Dissemination

by

Kenneth J. Kadow and Leon K. Jones

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FUSARIUM WILT OF PEAS WITH SPECIAL REFERENCE TO DISSEMINATION¹

by

Kenneth J. Kadow² and Leon K. Jones

INTRODUCTION

Whenever a pea producer, whether canner, seed grower, or market gardener, starts activities in a given area he often finds it very convenient to grow his crop repeatedly on the same ground, either with infrequent rotation or none at all. Obviously, this practice gives rise to increased troubles from plant diseases. It is generally conceded by authorities of the pea industry that pea diseases are partially responsible for the gradual movement of the pea-producing center from the eastern coast of the United States westward, and will no doubt be the motivating factor in its continued movement in that direction. Pea producers now recognize the importance of rotation and general sanitation, and consequently, any movement of the center of production will from now on be much slower. At the present time the five greatest canning states, from the standpoint of acreage, are Wisconsin, New York, Minnesota, Illinois, and Maryland (Table 1). The largest seed producing region is in the semi-arid northwest, the principal states being Washington, Idaho, and Montana. California is also an important pea seed producing state. While these are by no means the only canning or seed producing areas, they are the most important ones.

Since the first report of Fusarium wilt of peas, the disease has been spreading so rapidly that it was considered essential to determine some facts concerning the different methods of dissemination of the causative organism. From field observations and knowledge of the spread of similar diseases, several methods were considered as probably responsible for at least local dissemination, but there existed no good explanation for the spread to widely separated areas. The main purpose of these investigations was to prove experimentally how the pathogen is disseminated

¹These investigations were begun at the Washington State Agricultural Experiment Station and completed at the University of Illinois by courtesy of the Department of Horticulture. The writers wish to express their appreciation to Dr. B. L. Wade, Geneticist, for advice and the supply of many samples of pure line seeds; and to Dr. H. W. Anderson, Plant Pathologist, for many helpful suggestions and criticisms in carrying out the experiments.

²Portions of this manuscript submitted as partial fulfillment of requirements for the degree of Master of Science at the State College of Washington.

Table 1. Acreage of Peas Grown for Canning in Various Sections
of the United States¹

State	Acres planted to canning peas	
	1930	1931
Wisconsin	127,000	116,000
New York	34,400	33,800
Minnesota	17,900	17,180
Illinois	12,660	13,550
Maryland	13,000	13,260
Utah	13,070	6,540
Michigan	11,660	12,240
Indiana	6,270	6,270
Ohio	5,410	5,950
Colorado	3,700	3,770
Delaware	3,200	2,800

¹Estimated by the Bureau of Agricultural Economics, Division of Crop and Livestock Estimates of the United States Department of Agriculture.

and thus suggest methods of its control. During the progress of the work it was found expedient to investigate certain other points regarding the disease.

IMPORTANCE AND DISTRIBUTION

In the important canning states the general rootrot complex and Fusarium wilt are the two problems that are most actively threatening the industry. Fusarium wilt is the only disease that is of equally great importance to both canners and seed producers. It was first reported by Jones and Linford (2) in 1924 when they were able to separate it from the general rootrot complex in Wisconsin. In the northwestern seed producing region Fusarium wilt causes greater losses than all other pea diseases combined. Taking the entire country into consideration it is without a doubt the most important pea disease. When Linford (8) made his national survey in 1928 he reported the disease in Wisconsin, Michigan, Indiana, Maryland, Pennsylvania, Ohio, Illinois, Idaho, Montana, and possibly California. The last available report (17) has shown the disease to be present in California, northern Idaho, Washington, and Canada, in addition to the states mentioned by Linford.

Exact figures are not available as to the degree of infestation in most states, but conservative estimates made by Wade (17) for eastern Washington and northern Idaho placed it at not less than 5 to 10 per cent in 1929 on 21,500 acres. The infestation of the 1930 crop is gener-

¹Reference is made by number to literature cited on page 30.

ally agreed to have been at least as severe, which adds another 21,500 acres showing 5 to 10 per cent actual crop loss. The total pea producing area in eastern Washington and northern Idaho is between 120,000 and 150,000 acres, half of which produces peas in a given year. In 1931 estimates of loss over the same land that was surveyed in 1929 showed very definitely that 20 per cent or more of the acreage planted was wilt infested. The actual damage to the pea crop, however, was not proportionately increased in 1931 over 1929 to the increase in soil infestation, the reason being that nearly 3,000 acres of land which in 1929 scarcely gave the growers their seed back returned yields in 1931 of 50 per cent or more from partially resistant strains that were being used for seed by commercial seed companies on these heavily contaminated lands.

The actual crop loss varies from a few spots in a field to almost complete destruction. For example, about 3,000 acres of the total area showed killing from 85 to 95 per cent, while the remaining infested land averaged about 10 per cent loss. That this problem is very important is shown by the fact that the acreage in which the disease occurs has doubled in one crop year.

The disease was reported in the northern Idaho area for the first time in 1930. In 1931 it was found in trial grounds at Bonners Ferry, Idaho. The bulk of the damage so far is localized around Fairfield, Washington, although a few spots have been discovered as far south as Palouse (Plate I).

Since the first report of resistance by Wade (16) in 1929, some of the more important seed companies have been carrying on extensive experiments on the development of resistant varieties of high commercial value. Their experiments have been so extensive and complete that in the very near future several high-grade pea varieties that are highly resistant to Fusarium wilt should be available.

This disease was first recorded in Washington in 1928 from material sent from the pea seed-growing area near Fairfield, to the Department of Plant Pathology, Pullman, Washington, and was studied in more detail by the junior author in 1929. Inquiries made of the farmers, however, proved that the disease was present in this region at least four years prior to its identification. The first extensive survey and estimate of loss in Washington was made in 1929 by B. L. Wade, Mr. Cross, local manager of one of the seed companies in the Fairfield area, and the junior author. In 1931 B. L. Wade and the senior author, independently of each other, made further surveys of the pea wilt situation in Washington and northern Idaho to determine, if possible, the rate of increase of the disease and the total infested area. Also, in 1931 the federal government conducted field experiments near Fairfield, testing hundreds of varieties for resistance under the direction of Doctor W. J. Zaumeyer. This field test was in most respects a duplicate of the tests

carried out at Wisconsin by Walker (18), an account of which was published in 1931. Definite proof that *Fusarium* wilt of peas may be seed-carried was first established by Snyder (14) in 1931.

SYMPTOMS OF THE DISEASE

Collectively the symptoms of *Fusarium* wilt of peas in a field of susceptible varieties are such that once familiar with them a diagnosis under field conditions is relatively certain (Table 3). One of the most outstanding field symptoms in susceptible crop of peas is the irregular yellowish spotting that occurs in newly infested fields (Plate II). If, however, the disease is present in a field of highly resistant plants, no spotting is evident and an accurate diagnosis can be had only by supporting laboratory tests. Several of the symptoms associated with pea wilt seem to be constant under rather widely variable environmental influences, but many others seem to vary with environment. The lack of properly controlled greenhouse temperatures made experiments on factors influencing symptoms inconclusive; however, the work by Linford (7) and field observations seem to indicate that the most important single factor influencing symptoms is temperature. At temperatures below 65° to 70° F. symptoms are usually not in evidence; however, under western conditions symptoms are very evident at maximum soil temperatures as high as 88° F. Experiments at Wisconsin seem to indicate that temperatures above 77° to 80° F. were not favorable for the disease.

That other influences besides temperature affect symptoms is evident in the fields of the Fairfield area of Washington. In tests carried out by the federal government none of the seeds used were treated with a fungicide except the checks. In almost every instance the symptoms most typical of the disease (Table 3) in the West were present on the Semesan-treated seed, while the untreated material varied so much in symptoms that oftentimes plants were taken to the laboratory to make sure that wilt was killing them. Because of this great variation it was thought advisable to run a series under controlled conditions so they could be observed more closely. Two hundred pure line susceptible Alaska seeds were used in this test. The soil was from the Fairfield district and was known to be badly wilt-infested. Twenty Green Admirals were used as checks. One hundred of the susceptible seeds were Semesan-treated and the other 100 were untreated.

Because of the great variation that occurred in symptoms they were recorded as typical (+) or not typical (-). Every time a plant wilted it was taken to the laboratory and isolations were made from the lowest internode upwards including the seventh. In no instance was a fungus obtained above the sixth¹.

¹ Isolations made from plants grown in the field in the summer of 1931 never yielded fungi above the fifth node and most usually not above the fourth.

Table 2. Seed Treatment and Its Relation to Symptoms and Extent of Invasion by Wilt and Other Fungi^a

Isola- tion No.	Internode and result							Sym- ptoms	Isola- tion No.	Internode and result							Sym- ptoms
	1	2	3	4	5	6	7			1	2	3	4	5	6	7	
1	+	+	+	+				Typical	38	+	+	+	+				Typical
2	-	+	+	+	+			+	39	+	+	+	+				+
3	-	+	+	+	+			+	40	-	+	+	+	+			+
4	+	+	+	+				+	41	+	+	+	+	+			+
5	+	+	+	+				+	42	-	-	+	+				+
6	+	+	+	+				+	43	-	-	+	+				+
7	-	+	+	+				+	44	-	-	+	+	+			+
8	-	+	+	+	+			+	45	+	+	+	+				+
9	-	-	+					+	46	+	+	+	+				+
10	-	+	+	+				+	47	+	+	+	+				+
11	+	+	+					+	48	-	-	+	+				+
12	+	+	+	+	+			+	49	-	-	+	+				+
13	+	+	+	+				+	50	-	-	+	+				+
14	-	+	+	+	+			+	51	-	-	+	+				+
15	-	-	+					+	52	+	+	+	+				+
16	+	+	+	+				+	53	+	+	+	+				+
17	-	+	+	+				+	54	-	-	+	+				+
18	+	+	+	+	+			+	55	+	+	+	+				+
19	+	+	+					+	56	-	-	+					+
20	-	+	+	+				+	57	+	+	+	+				+
21	+	+	+	+	+	+		+	58	-	-	+	+				+
22	-	+	+	+	+			+	59	-	-	+	+				+
23	+	+	+	+				+	60	-	-	+	+	+			+
24	+	+	+					+	61	-	-	+	+				+
25	-	-	+					+	62	-	-	+	+				+
26	+	+	+					+	63	+	+	+	+				+
27	-	+	+	+	+			+	64	-	-	+	+	+			+
28	-	-	+					+	65	-	-	+	+	+			+
29	+	+	+					+	66	+							+
30	-	-	+					+	67	-	-	+	+				+
31	+	+	+					+	68	+	+	+	+				+
32	-	-	+	+				+	69	-	-	+	+				+
33	-	-	+	+	+			+	70	+	+						+
34	-	-	+					+	71	+	+	+	+				+
35	+	+	+					+	72	+	+	+					+
36	+	+	+	+				+	73	-	-	+	+				+
37	+	+	+	+				+	74	+	+	+					+

^aPure line susceptible Alaska seeds used. This series of 100 seeds was Semesan-treated.

If a fungus was obtained that culturally looked like the wilt organism, it was recorded as (+); if it was mixed with other fungi it was recorded as (-). Isolations were made from 69 plants from untreated seeds and 74 from treated seeds. Isolations were usually made from five to nine days after the first symptoms appeared. All 74 of the plants from treated seeds gave typical symptoms (Table 2). Isolations from these plants gave cultures comparable to the wilt fungus with the exception of the

lowest internode in 38 instances and the second lowest in 11 which were overrun with bacteria and secondary fungi. *Fusarium martii* App. & Wr. var. *pisi* F. R. Jones (1) was quite abundant in these cases. Of the 69 isolations made from plants of non-treated seeds, 22 gave typical symptoms (Table 2-A) and cultures similar to the wilt cultures used for comparisons from all but the lowest internode in 14 cases. The other

Table 2-A. Seed Treatment and Its Relation to Symptoms and Extent of Invasion by Wilt and Other Fungi¹

Isola- tion No.	Internode and result							Sym- ptoms	Isola- tion No.	Internode and result							Symp- toms
	1	2	3	4	5	6	7			1	2	3	4	5	6	7	
1	+	—	—	—	+			—	36	—	—	+	+				—
2	—	—	—	—	+	+		—	37	—	—	—	—				—
3	—	—	—	—	+	+		—	38	—	—	—	—				—
4	—	—	—	—	+	+		—	39	—	+	+	+	+			+
5	—	—	—	—	—	+		—	40	—	—	+	—	+			+
6	+	—	—	—	—	—		—	41	—	—	+	+				—
7	—	—	—	—	—	+		—	42	—	—	—	—				—
8	—	—	+	+	+	+		—	43	—	—	—	—				—
9	—	—	+	+	+	+		—	44	—	—	+	—				—
10	—	—	+	+	+	+	+	—	45	—	—	+	+				—
11	—	—	—	+	—			—	46	—	—	+	—				—
12	—	—	—	—	+	—		—	47	—	—	+	—				—
13	—	—	—	+	—			—	48	—	—	+	+				—
14	—	—	—	—	—			—	49	—	—	—	—				—
15	—	—	—	—	—			—	50	—	—	+	+	—			+
16	—	—	—	+	—			—	51	—	—	+	—	+	—		+
17	—	—	—	—	+	—		—	52	—	—	+	+	+	+		+
18	+	—	—	—	—			—	53	—	—	—	+				+
19	+	—	—	—	—			—	54	—	—	+	+	—			+
20	—	—	+	+	+	+		—	55	—	—	+	+				+
21	+	—	—	—	—			—	56	—	—	+	—				+
22	—	—	—	—	—			—	57	—	—	+	—				+
23	—	—	—	—	—			—	58	—	—	+	—				—
24	—	—	—	—	—			—	59	—	—	+	—				—
25	—	—	—	—	—			—	60	—	—	—	—				—
26	—	—	—	—	—			—	61	—	—	—	+				—
27	—	—	—	—	—			—	62	—	—	—	—				—
28	—	—	—	—	—			—	63	—	—	+	+	—			+
29	—	—	—	—	—			—	64	—	—	—	+				+
30	—	—	—	—	—			—	65	—	—	+	—				+
31	—	—	—	—	—			—	66	—	—	+	+				—
32	—	—	—	—	—			—	67	—	—	—	—				—
33	—	—	—	—	—			—	68	—	—	+	—				—
34	—	—	—	—	—			—	69	—	—	+	—				—
35	—	—	—	—	—			—	Che	cks ²							

¹ Pure line susceptible Alaska seeds used. This series of 100 seeds was not Semesan-treated.

² Twenty Green Admiral plants grown on wilt-infested soil were used as checks. All remained healthy.

Table 3. Comparative Symptoms of Fusarium Wilt of Peas

Linford's Wisconsin symptoms (7)	Symptoms in Washington and Idaho from plants from Semesan-treated seed
Recurving of younger leaflets and stipules	Not so pronounced; may be entirely lacking
Upper part of plant may become pale	Observed in about 50 per cent of the cases; usually accompanies recurring
Develops a bluish sheen	Not observed by the writers. Wade (17) reports it rarely
Terminal bud may be checked in its growth	May be checked slightly
The stem and upper leaves may become more rigid than normal	True if plants are killed when small. Seldom noticeable on older plants
Lower leaves turn pale and commence to wither	Very common symptom
Characteristically, however, after collapse of few basal leaves the upper part of the plant wilts abruptly, may become dry while still green in color	Plants slow to wilt—may retain green color, especially ones killed late in season
After such wilting, stem shrivels from the tip toward basal internodes	The same
Unilateral symptoms—disease may affect one side before affecting the other	Never observed by the writers. Wade reports it rarely
Roots show a few dead rootlets and limited browning but otherwise white and clean externally	Quite common to have limited browning on rootlets. Few, if any, dead. (This observation made in greenhouse tests)
Vascular discoloration in upper part of tap root and may extend to lower internodes	Vascular discoloration seldom visible even in tap root
In wet soils succulent cortex of the basal internodes may become covered with fluffy growth of mycelium	This growth never observed on basal internodes—often observed on tap root of early killed plants
Plants may wilt in 2 days after first symptoms. Ten to 12 days usually necessary	Great abundance of spores on tap root of early killed plants if tap root is soft and cortex partially sluffed; not so on hard firm roots
Basal internode becomes distinctly swollen	Ten to 15 days and usually many more
	Swelling never observed by the writers. Wade has in a few instances observed it

47 isolations, however, gave non-typical symptoms and typical wilt cultures only from the highest internode with 11 exceptions which gave them from the second highest. All the other isolations were overrun with other fungi. Field observations and this experimental evidence both indicate that other fungi, whether mildly parasitic or not, play an important role in relation to wilt symptoms. They also indicate that Semesan tends to inhibit the invasion of the plant by other fungi, but plays no part in checking invasions by Fusarium wilt that is already established in the soil. The checks (Table 2-A) in this experiment all remained healthy.

No uniform difference in symptoms was observed by comparing plants grown on inoculated, sterilized, brown silt loam soil with inoculated, sterilized sandy loam soil. On account of the sterilization of the soil and the limited types used, this test cannot be considered conclusive although it indicates that soil differences are not as important to expression of symptoms as temperature and other fungi in the soil.

An excellent list of other pea diseases caused by species of Fusarium is given in the recent works of Jones (1) and Linford (7). None of the other Fusarium diseases of peas would likely be confused with pea wilt as caused by *F. orthoceras* var. *pisi*; consequently, no treatise of them will be attempted in this paper.

HOSTS

The principal hosts of *F. orthoceras* var. *pisi* is *Pisum sativum* L. However, not all varieties of *P. sativum* are susceptible to Fusarium wilt, but generally speaking the most desirable canning and market garden varieties are susceptible. Additional hosts of the disease are *Vicia gigantea* Hook., a native perennial vetch from California and Nevada, and under some conditions *Vicia fabae* L., Sutton's New Giant Broadbean, is also invaded. These are the hosts originally described by Linford (7). No reports on additional hosts have yet been made.

CAUSAL ORGANISM AND ITS LIFE CYCLE

The causal organism of Fusarium wilt of peas is *Fusarium orthoceras* App. and Wr. var. *pisi* Linford, of the section Elegans (13 and 19). Linford (7) has shown the fungus to be primarily a vascular parasite with the principal invasion in the xylem although phloem and the elements around both xylem and phloem are often slightly invaded. He further states that the fungus enters the plant through rootlets and then passes through cortical and undifferentiated tissue to gain entrance into the vascular elements. Aside from these occasional rootlet entries, there are no conspicuous cortical lesions as is quite often the case with invasions by soil organisms.

Under proper field conditions the wilt organism often produces a great many spores on the partially sluffed cortex of plants killed early

in the growing season (Plate III). All of the spores in Plate III are not from the wilt organism, but pathogenicity tests from part of the same material used for the picture gave the wilt fungus in about 60 per cent of the cases. The macroconidia, shown in this figure, are the type used for the single spore isolations discussed on page 19 under Pathogenicity. Microconidia usually outnumber the macroconidia about 15 to 1. The macroconidia usually have three but often four septae and the micronidia none. Most of the spores in Plate III showing one and two septations are spores of other fungi, most generally other Fusaria. In culture the pea wilt organism seldom sporulates, although it usually forms great numbers of chlamydospores. Linford (7) gives a detailed explanation of the morphology and cultural appearance of the fungus.

It is generally agreed by those familiar with the disease that the fungus remains viable in the soil for several years, thus making rotation a rather inadequate means of control once the fungus has become established. An accurate statement of how long the fungus remains viable in the soil is not available at this time. The most important means of dissemination are discussed in full later in this paper.

PATHOGENICITY

No detailed studies have been reported so far that have adequately tested different isolation for possible physiologic forms of the organism. There is evidence, however, that some variation of host selection by the fungus exists. Linford (7) reports that from 118 inoculations made only 75 gave positive results. In experiments by the writers, it was possible to get single spore cultures from spores (Plate III) taken from partially studded cortex of plants killed early in the growing season. Three series (Table 4), each from single spore isolations with six sub-cultures from each single spore culture, were grown on sterilized oats and inoculated into wilt-free soil. Pure line susceptible Alaska peas were planted in this inoculated soil. In series 1, only 46 of the 78 plants were killed; all of the plants in two of the six pots involved remained healthy. Careful examination of the cultures used in the duplicate tests gave no clue to a possible explanation, although the results were quite similar. In all but one case (Pot 6 Series 1) either all plants or none were killed in a given pot. In Pot 1 Series 3, five plants were still apparently healthy after 28 days, but were killed shortly thereafter.

To test for possible physiologic forms, Perfection variety peas were planted in the pots that had given negative pathogenicity tests on pure line susceptible Alaska, but after 30 days the plants showed no symptoms of the wilt disease. Further tests for host selection by the fungus were not made.

Fifty isolations were made from plants showing symptoms of the disease during the summer from different wilt-infested areas. These

Table 4. Pathogenicity Tests of Cultures from Single Spore Isolations of the Pea Wilt Fungus¹

Series No.	Plants up			No. killed in 28 days			Isolation results		
	I	II	III	I	II	III	I	II	III
Pot No. 1	12	10	15	12	10	10	positive	positive	positive
Pot No. 2	14	11	14	14	0	14	positive		positive
Pot No. 3	11	15	14	11	15	14	positive	positive	
Pot No. 4	15	15	15	0	15	0	positive	positive	positive
Pot No. 5	15	15	10	0	15	0	positive	positive	positive
Pot No. 6	11	10	10	10	10	10	positive	positive	positive
Control 7	14	11	13	0	0	0	0	0	0

¹ Pure line susceptible Alaska peas were used in this test.

isolations had similar cultural characters to those exhibited by *F. orthoceras* var. *pisi*. Tests with these isolations gave only 36 positive pathogenicity tests on the Perfection variety peas. Further tests of these same cultures on Horsford, Surprise, Thomas Laxton, and pure line Alaska all gave similar results.

In the early part of the summer of 1931 some diseased Blue Bantam variety peas were sent to the Department of Plant Pathology at the State College of Washington. Nineteen different isolations from this material gave cultures with similar characters every time; seven additional isolations were badly mixed with bacteria and were discarded. The fungus that was repeatedly isolated ran true to type, and in every case was morphologically and culturally different from Linford's pea wilt organism. Tests on the pathogenicity of this organism involving several different varieties of peas in all cases were negative. It may be possible that temperature and moisture requirements for best development of this fungus are so different as compared with *F. orthoceras* var. *pisi* that the plants were protected. On the other hand, Blue Bantam variety pea may be one of only a few varieties that it attacks. Space and time would not permit further experiments along this line. It would seem that physiologic forms are a plausible explanation for the different variations observed by those familiar with the disease, even though attempts thus far have failed to establish their existence.

DISSEMINATION

Since the Fusarium wilt of peas was first observed in 1924, a knowledge of the methods of dissemination has been recognized as fundamentally important. At the time the writers started these experiments no definite information on this phase of the problem was available, although Linford (7) mentions several possible means. Recently, experiments by

Snyder (14 and 15) established seed dissemination of the disease. It has been demonstrated repeatedly in relation to similar soil organisms that spread within a given field or vicinity may be due largely to implements involved in farm practices, i. e., plowing, cultivating, discing, etc. It is also obvious from field observations that run-off water from severe rains plays a certain role in dispersing the organism. While the above explanations may suffice for local disseminations, they certainly cannot be responsible for the rapid appearance of the disease in widely separated regions. Seed transmission would appear to be logical explanation of the appearance of the disease in these areas. Considering western harvesting practices, the threshing machine may be responsible for new appearances of the disease within a radius of 15 or 20 miles. In one instance, in the summer of 1931 a threshing outfit after harvesting from a severely infested field was moved about 16 miles to harvest a crop that was free from the disease. Birds feeding upon worms and loose pea seed may be considered as possible agents of disseminations.

Dissemination by Seed

Because of the recent bibliography of seed-borne parasites by Orton (12), it seems unnecessary to repeat the list of *Fusarium* seed-borne diseases cited by him. Since his work, two additional references of importance to this paper have appeared. Kendrick (5) has proved seed dissemination of *Fusarium* wilt of cowpea and Snyder (14 and 15) demonstrated the same for *Fusarium* wilt of peas. The literature contains experimental proof of seed dissemination, either internal or external, of specific *Fusarium* diseases in more than 30 different instances. Several other cases are reported in which the species of the *Fusarium* is not known.

In planning experiments on seed dissemination the writers considered the following points: Is the fungus seed-borne? If so, is it carried internally or externally? If it is carried by the seed, when and how does it become associated with them, and how long a time after it is introduced in a wilt-free field must elapse before the organism becomes sufficiently established to produce disease in plants?

Five thousand seeds were collected from a badly infested field after harvest and were thoroughly cleaned by an electric fan. The seeds were then planted in soil known to be wilt-free. They were allowed to grow about 25 days from the time they first appeared above ground, after which time they were pulled up and a new series planted. In the succeeding plantings, however, only 1000 pure line susceptible Alaska seeds from wilt-free ground were used; as a further precaution they were sterilized with 50 per cent alcohol for 10 minutes and allowed to dry before being planted. The checks in this experiment were surface-sterilized Perfection seeds, also from wilt-free ground. The only means of soil contamination in this experiment was from the 5,000 seeds planted in Series 1 on

Table 5. Test for Seed-Carriage of Pea Wilt and Time Required to Give Killing Following Introduction into Wilt-Free Soil

Series number	Seed source	Variety	Seed treatment	Number planted	Points of infestation in seed bed	Infection result
1	Heavily infested field	Winners	Cleaned with fan—not sterilized	5000	None	
2	Wilt-free field	Alaska (pure line)	Sterilized with alcohol and dried	1000	None	
3	Wilt-free field	Alaska (pure line)	Sterilized with alcohol and dried	1000	1*	
4	Wilt-free field	Alaska (pure line)	Sterilized with alcohol and dried	1000	1*	
Checks	Wilt-free field	Perfection	Sterilized with alcohol and dried	250 ¹	None	

¹ Each time a new series was run 250 new checks were planted.

² Diameter of spot in which plants were killed was about 3 inches.

³ Diameter of spot in which plants were killed was about 5 inches.



PLATE 1
Map of eastern Washington showing the distribution of wilt-infested land
in the pea-seed growing area.

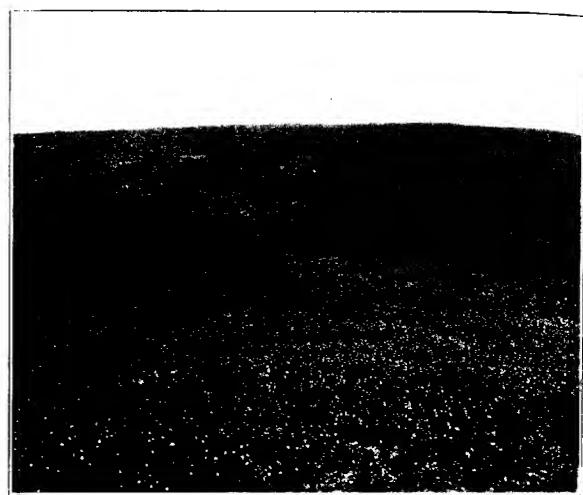


PLATE II

A commercial field of a susceptible variety of peas on wilt-infested soil showing numerous areas of wilted plants. Wilt areas outlined.

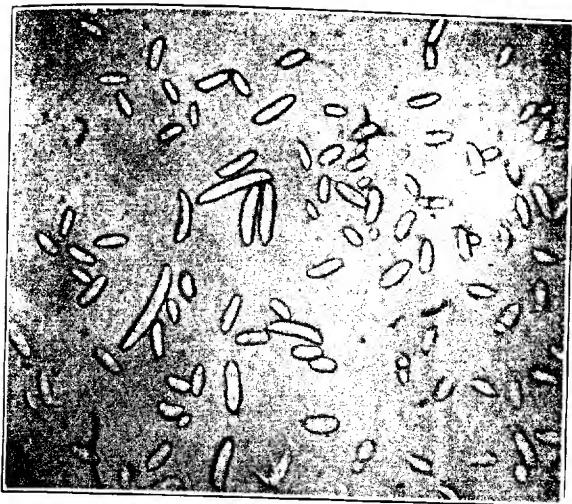


PLATE III

Spores taken from partially sloughed cortex of several early killed plants.
Plates poured from same dilution and pathogenicity of a few typical cultures
showed most of the spores to be **Fusarium orthoceras** App. & Wr. var. *pisi* Linford.
About 40 per cent of the spores were of other fungi, mostly other Fusaria.



PLATE IV

Susceptible and resistant varieties of peas grown in wilt-infested soil (Photograph by courtesy of Dr. B.L.Wade).

(Left) Susceptible variety—cross between Dwarf Giant by Gradus.
(Right) Resistant variety—pure line Alcross.

disease-free soil. It will be seen from Table 5 that killing occurred in only one place in the seed bed and in the third series of peas. The same spot gave killing in the fourth series. Cultural comparisons of the isolated fungus showed it to be the wilt organism. Check plants showed no symptoms.

The above experiment is quite similar to that conducted by Snyder (14 and 15) to determine whether or not seed from infested fields carried the disease. He planted unsterilized seed from badly wilted crops in each successive planting but did not get killing until the fourth planting at which time killing appeared at four different points in the seed bed.

The experiments by Snyder and the writers establish that the disease is seed-borne, but the exact manner has not definitely been proved.

All the seeds used in testing for internal seed-carriage were from commercial plantings suffering heavy losses from wilt and harvested by combine except where otherwise stated. The seeds were sterilized externally by the same method as used by Jones (3) in his studies of the Ascochyta diseases of peas. In brief, one gram of calcium hypochlorite is used to every 14 cc. of distilled water. The mixture is stirred frequently and after 15 minutes it is filtered. The peas are allowed to stand with frequent stirring for about four and one-half hours in five times their volume of the filtrate. After this treatment the filtrate is poured off, and from 300 to 500 seeds are placed in each of several damp chambers which have about one-half inch of two per cent potato dextrose agar over the bottoms. A large bell jar is placed over the chambers after the seeds are poured into them. The damp chambers are held at room temperature for from 8 to 10 days, which seems to be sufficient time for any organism within the seed coat to grow out into the media. After 10 days a careful examination of the fungi for the presence of Fusaria is made. The results of this experiment are given in Table 6.

In considering internal seed-carriage there are two ways in particular which might, under some conditions, make it possible for the pathogen to enter the pea seed. The more likely is the falling over of the pea plant so that its pods lie on moist and heavily infested ground. The season of 1931 was very dry in the Pacific Northwest; consequently, no experiments to prove this point were devised. Direct invasion through the vascular elements of the plant may come into play in an exceedingly wet growing season. Linford (7) reports the disease as being present frequently in the fifth and sixth internodes, but never within two nodes of the lowest pod. Snyder (15) reports that in one instance out of 50 he isolated the fungus from the stem internode immediately below the attachment of the lowest pod, but failed to isolate the organism from the pedicel and seeds of the lowest pod.

Table 6. Results of Tests to Determine Whether the *Fusarium* Wilt Organism Is Carried Within the Seed

Series number	Seed source	Kind of seed	Number of seed	Bacterial colonies	Fungous colonies	Pathogenicity test results	
						Fusaria present	
1	Walter's—Fairfield, Wash.	Winners	1500	2	1		
2	Houlestein's—Fairfield, Wash.	Alaska	1000	1	0		
3	Koontz's—Fairfield, Wash.	Alaska	1000	2	0		
4	Wisconsin grown	Alcross	2000	8	4		
5	Walter's—Fairfield, Wash.	Winners	2000	0	0		
6	Koontz's—Fairfield, Wash.	Alaska	1000	0	1		
7	Wisconsin grown	Alcross	1500	1	2	1-Fusarium like	Negative
8	Wisconsin grown	Alcross	2000	2	7		
9	Wisconsin grown	Alcross	3000	4	10	4-Fusarium like	Negative
10	Koontz's—Fairfield, Wash.	Alaska	2000	2	1		
11	Walter's—Fairfield, Wash.	Winners	2000	1	2		
12	Houlestein's—Fairfield, Wash.	Alaska	1500	0	1		

Out of more than 100 attempts the writers did not isolate the fungus from field plants grown at Fairfield, Washington above the fifth internode and seldom above the fourth. It may be seen, however, from Tables 2 and 2-A that plants grown in the greenhouse yielded the fungus several times from the sixth internode. This difference is interpreted to be in direct relation to the growing conditions under which the plants developed. To study the effect of nearly moisture saturated air and soil on the invading power of the fungus, several infected plants that had produced their first pods were placed under a large bell jar and isolations were made from two to four days after each plant had wilted. In almost every instance the fungus was obtained from the pedicel of the lowest pod and in 21 cases from the suture of placentation. The seeds aseptically removed from the pods with infected sutures did not yield the fungus.

While internal seed-carriage of the fungus might be possible under some conditions, it is very doubtful that it ever occurs in the field unless entrance is gained to the seed by pods which come in contact with infested soil. The pods used for the experiment recorded in Table 7 were all hand picked from plants that were lying on the ground. The pods were taken only when they were in contact with soil of infested fields, which at the time the pods were collected was very dry. These pods were then

Table 7. Results of Tests to Ascertain if Fungi Enter Pods that Are in Contact with Soil¹

Series number	Number of pods and seeds	Kind of seed	Organisms present	Fusarium present
1	200 pods 517 seeds	Alaska	2 fungi 7 bacteria	None
2	200 pods 604 seeds	Alaska	1 Alternaria and 1 Cladosporium 5 bacteria	None
3	206 pods 619 seeds	Alaska	4 fungi 9 bacteria	None
4	210 pods 564 seeds	Perfection	1 Alternaria 5 bacteria	None
5	198 pods 496 seeds	Perfection	3 fungi 4 bacteria	1 <i>Fusarium martii</i> var. <i>pisi</i>
6	154 pods 390 seeds	Perfection	4 fungi 2 bacteria	None

¹ Season and soil very dry. Seeds aseptically removed from pods.

taken to the laboratory and the seeds removed aseptically and placed on two per cent potato dextrose agar to allow organisms present to develop.

It may be seen from this experiment that fungi do occasionally enter seeds when the pods are in contact with soil for some time. While treating seeds for internal carriage of *Ascochyta sp.*, Jones (3) also found that *Fusarium spp.* were occasionally carried in this manner. Under moist conditions pod invasions by *F. orthoceras* var. *pisi* may become very numerous. The frequency with which other fungi were encountered in the above experiment, as shown by Table 7, makes further work on this point seem desirable.

In considering external seed-carriage of Fusarium wilt of peas, several points of interest might well be investigated. The disease may be carried on or in cracks on the seed coat, as spores, chlamydospores, or even as fungous mycelium. Also particles of infested soil or broken fragments of infected plants may be carried with the seed. The possibility that this may occur is very likely since even seeds cleaned at large seed company warehouses often carry small hard particles of dirt with them.

The following experiment was designed to determine whether or not the wilt organism is carried with the seed and externally of the seed coat. Kendrick (5) proved that the machine methods of harvesting play an important role in mixing the pathogen with the seed in the study of Fusarium wilt of cowpea. This point seems very significant in relation to Fusarium wilt of peas. The spores of the fungus and fungous mycelium enter the threshing machine with the pea plants and might easily be blown through the spout into the sack of pea seeds. That this is probably the most important method of seed contamination is shown by Table 8.

A total of 29,000 seeds, all from badly infested fields, were tested for the presence of the Fusarium wilt organism on the outside of the seed. The pods of 2,600 seeds were hand picked from vines killed after they had produced their first pod as were also the 3,190 seeds mentioned in Table 7. The death of the plants allowed the pods to come in contact with soil of infested fields. None of the 5,790 hand picked seeds yielded the fungus although it is possible that further tests may have given positive results since other fungi were present in several cases. Of the 29,000 seeds of Table 8, the remaining 26,400 were harvested by a threshing machine from fields showing severe loss from wilt. In this experiment the seeds were placed in about one and one-half their volume of sterile distilled water and thoroughly agitated to free fungous spores or soil particles that might be lodged on the seed. After 15 minutes the wash water was plated on two per cent potato dextrose agar with enough lactic acid added to keep down bacterial growth. Usually from one to two cc. of the wash water was poured in each plate. Any fungous colonies that looked like the Fusarium wilt organism were transferred and their pathogenicity tested. In the washings and cultures from the 29,000

Table 8. Test for Fusarium Wilt of Peas in Relation to External Carriage

Date of run	Number of seeds	Seed source	Variety	Fusarium present	Pathogenicity
5/13/31	300	Wade	Perfection ¹	1 Fusarium	—
5/20/31	300	Wade	Perfection ¹	1 Fusarium	—
6/ 9/31	900	Koontz	Alaska	None	
6/11/31	2100	Koontz	Alaska	1 Fusarium	+
6/24/31	1500	Koontz	Alaska	None	
7/10/31	2000	Koontz	Alaska	None	
10/26/31	2000	Walters	Winners	5 Fusaria	1+
11/ 9/31	2000	Walters	Winners	Acid too strong No growth	
11/19/31	4000	Walters	Winners	None	
11/26/31	2000	Walters	Winners	None	
12/20/31	1500	Walters	Winners	None	
12/31/31	2000	Walters	Winners	2 Fusarium martii	
1/ 6/32	2500	Walters	Winners	7 Fusaria	1+
1/11/32	2000	Walters	Winners	None	
1/24/32	2000	Koontz	Alaska	None	
2/ 1/32	2000	Houlstein	Alaska ¹	None	

¹ Hand picked pods; all others harvested by threshing machine. All produced at Fairfield, Washington.

seeds, three colonies of *F. orthoceras* var. *pisi* were obtained. It was proved by inoculation of wilt-free soil that the organism isolated in each of the three cases was pathogenic on pea plants. Increases of the three fungi tested were made on sterilized natural oat media. After three large pots of wilt-free soil were inoculated with the cultures, 15 pure line Alaska seeds were planted in each of them; 39 of the plants came up and all were killed by wilt. Reisolations from six plants, two from each pot, showed the fungi to be the same as those used for the inoculum. Ten of the same lot of seed were planted on wilt-free soil and were used as checks. Nine of the plants came up and all remained healthy.

Snyder (14 and 15) reports four separate cases of wilt developing from about 10,000 seeds from wilted fields. Observations by the writers made in fields showing wilt for the first time indicate that in a field, using the same lot of seed for entire planting, points of infestation will often average from one to as high as three per acre. There are about 125,000 Alaska seeds to a bushel and plantings range from one and one-half to five bushels per acre, with two bushels an approximate average in the West.

In Illinois, Wisconsin, and other central states, four bushels to the acre of the smooth varieties and five of the wrinkled sweets are usually planted. When four bushels of Alaska are used there would be nearly 500,000 seeds to every acre. It is very doubtful if seeds for commercial plantings are often as heavily infested as those used by Snyder and the writers for their experiments, but, if normal seed-carriage from infested fields was only about one-fifteenth of that reported by the above experimenters, the dissemination would exceed the actual conditions observed by the writers. From field observations and experiments it would seem that seed dissemination of Fusarium wilt of peas is probably one of the most important methods of its spread, especially into widely separated areas.

In early November, 1931, 100 Alaska seeds were thoroughly washed and sterilized in alcohol and, after they had dried, they were atomized with a spore suspension made from scrapings from the base of early-killed plants. Two days after the seeds were atomized they were fanned for one-half hour with an electric fan to free them from small particles of infected plant tissue. They were then placed in a flask and stored till late March, 1932, after which time each seed was placed, one at a time to assure their freeness from dirt and plant debris, on two per cent dextrose potato lactic acid agar.

The object of this experiment was to ascertain whether or not the wilt-fungous spores would live through the winter under storage conditions free from dirt and plant debris.

Of the 100 seeds discussed above, nine gave typical colonies, from a cultural and morphological point of view, of the Fusarium wilt organism. Cultures that were so badly mixed with other fungi that no attempt to separate them was made were obtained from 26 seeds. The remaining 65 seeds remained sterile.

The results are inconclusive because the seeds were stored in a laboratory store room which is considerably different from a seed company's or farmer's storage plant. They do indicate, however, that the spores do not readily become dessicated and may adhere directly to a seed coat.

Dissemination by the Threshing Machine

Considering the disease in the seed-producing areas, the threshing machine is one of the principal means of its spread. Diseased plants and infested dirt enter the machine at one spot in a field and may be dropped several hundred feet away on heretofore wilt-free soil. Also, dust and fragments of diseased plants collect on the machine and may be carried miles away to other fields. Through the wholehearted cooperation of several of the leading farmers of the Fairfield area, samples of dust from threshing machines were collected at different times after infested fields had been harvested.

The dust samples were mixed one to one with wilt-free soil and planted to susceptible plants (Table 9). As soon as the plants died, isolations were made. Few plants died in the first series, but many wilted in the second series of plants grown in the same pots. The checks remained healthy.

From these results it would seem that after harvesting over land known to be infested with wilt, the threshing machine should be thoroughly cleaned before it is moved to harvest on wilt-free soil.

Dissemination by Feeding Practices

It is a general practice in the Fairfield area to collect the pea plants after harvest and feed them to livestock. The manure is usually returned to the fields. With the aid of Mr. Hayes and Mr. Houlstein, both Fairfield farmers, two horses were penned up for two days without feed but with plenty of water. They were then fed on plants that had been killed by *Fusarium* wilt. The feces were mixed with wilt-free soil and Perfection peas were planted. The killing shown in Table 9 for this experiment was due to damping off fungi and not the wilt organism.

This experiment was designed to determine whether or not the wilt spores remained viable after passage through the digestive tract of the animals. The plants grew very rapidly and were exceedingly vigorous in appearance. Except for two plants killed in the seedling stage in Series 1 by a root rotting complex, all remained healthy.

The possibility of birds spreading the disease for great distances should not be overlooked. They feed upon worms and pea seeds from infested fields and may pass the remains many miles from an infected area. At the time this experiment was attempted, no wild birds were available and White Leghorn chickens were used instead. The chickens were not fed for 24 hours and then one of them was fed only pea seeds which had been thoroughly mixed with scrapings from early killed plants. The other was fed on an oat culture of the fungus which had great quantities of chlamydospores present. Both chickens were fed for two days and the feces collected for the second day and for one day after feeding was discontinued. A small quantity of spores of *F. martii* var. *pisi* were mixed with both feedings to see if they would pass through the birds since these spores are thick walled and appear to be very resistant.

The feces were mixed thoroughly with sterile distilled water and plated on two per cent potato dextrose agar in which enough lactic acid was added to prevent the development of bacteria. The spores of *F. martii* var. *pisi* remained viable but no colonies were present that were typical of *F. orthoceras* var. *pisi*.

Table 9. Dust from Threshing Machines and Feeding Practices and Their Relation to Dissemination of Pea Wilt¹

Material used	History of the material used	Pot No.	Series 1			Series 2		
			Up	Killed	Isolation results	Up	Killed	Isolation results
Dust from thresher	Collected about 2 weeks after harvest	1	15	0		11	8	+
		2	14	0		16	12	+
		3	12	0		14	0	
		4	14	0		9	9	+
		5	11	1	Rhizoctonia	12	3	+
Dust from thresher	Collected from combine 1 year after harvest of badly wilted field	1	8	8	All plants rotted in seedling stage—not wilt	7	6	Same as Series 1—no records taken
		2	5	5		3	3	
Dust from thresher	Material collected at harvest time	1	13	2		14	12	
Dust from thresher	Collected shortly after harvesting badly wilted crop	1	12	0		14	11	+
		2	15	4		13	13	+
Dust from thresher	Collected after 300 acres of wheat had been harvested	1	14	0		12	0	
Checks	Seed planted in same soil used for mixing with material	1	15	0		14	0	
Feeces from horses	Wilted plants collected and fed to animals under controlled feeding conditions—Feeks mixed with dirt	1	14	0		12	0	
		2	11	0		15	0	
		3	11	0		15	0	
		4	15	0		14	0	
		5	14	1		14	0	

¹ Name pots and material used for both series. Seeds used in this test were Perfection and Brannon.

The wilt organism may have been killed outright in the digestive tract of the chickens, or the true cultural characters of the wilt fungus were obliterated by scores of Penicillia and other fungi that were so predominant on the culture plates.

Dissemination by Wind

The exact role played by the wind in the dissemination of pea wilt is not known. It has been observed that plants killed by the fungus are often carried distances beyond observation by whirlwinds and wind storms. When the soil is dry it is blown freely by high winds, and there is little doubt that spores of the wilt fungus may be blown some distances with it. Due to the dryness of the soil, the frequent high winds which prevail in the Pacific Northwest may play an important part in the rapid spread of the disease. Field observations support this contention.

CONCENTRATION OF THE FUNGUS AND TIME REQUIRED FOR ORGANISM TO GIVE KILLING

In checking on the origin of seed with relation to the first appearances of Fusarium wilt of peas in a given field and results obtained by the writers (Tables 5 and 10), it appears that under normal field conditions the organism requires at least one year after being introduced to establish itself enough to give killing. Whether this requirement is due to a lack of quantity of the fungus or to relation with other soil fungi has not yet been ascertained. Linford (10) shows that heavily infested soil may be mixed with wilt-free soil at a ratio of one infested-soil part to 32 wilt-free soil parts and killing will still be obtained. A duplicate of Linford's experiment by the authors of this paper involving only unsterilized soil gave similar results in all but one case. Out of 15 susceptible plants in a dilution of 1 to 64, three plants died of wilt. These experiments would indicate that a very small quantity of the fungus is all that is needed for immediate killing, but the following experiment by the writers (Table 10) seems to indicate that establishment in the soil is more important than quantity although quantity has apparently a direct relation on the time required for establishment of the fungus. Large amounts of the fungus mixed with soil usually give killing the first time peas are planted in it, but not always.

In the soil dilution experiments by Linford and by the writers, no definite concept of the actual number of spores or amount of mycelium in each dilution could possibly be had. In the following experiment the authors have shown in a rather vague way just how much of the fungus must be present to give killing. There are a great many shortcomings in this experiment, but to those especially interested in Fusarium wilt of peas it may have some significance.

Table 10. Amount of fungus and Time Required to Give Killing of Pea Plants Grown from Untreated Perfection Seed

Number of squares	First planting			Second planting in same pots		
	No. of plants		Isolation results	No. of plants		Isolation results
	Up	Killed		Up	Killed	
Series I	1	2	0		5	0
	2	2	0		5	0
	4	3	0		4	1
	8	1	0		5	3
	16	2	2	+	5	1
	32	2	0		5	1
	64	2	0		4	2
	128	2	1	+	3	4
	256	2	0		5	2
	Checks	12	0		10	0
Series II	1	2	0		4	0
	2	2	1	+	4	2
	4	2	1	+	5	2
	8	2	0		5	0
	16	2	0		5	2
	32	2	0		5	3
	64	2	1	mixed	5	4
	128	2	2	+	5	5
	256	1	1	damped off	5	5
	Checks	10	0		8	0
Series III	1	2	0		5	0
	2	1	1	+	4	0
	4	2	0		5	0
	8	2	0		4	2
	16	1	0		5	5
	32	2	2	+	4	3
	64	2	0		5	4
	128	2	1	+	5	1
	256	2	0		5	2
	Checks	10	0		9	0

The wilt organism was grown on very thin layers of two per cent potato dextrose agar for three weeks at its optimum temperature. A razor was then used to cut the cultures into one-eighth inch squares. Pots were filled with wilt-free soil and one square placed in the first and doubled in each pot thereafter until there were 256 squares in the last pot. A small hole was made in the soil in which the squares were placed. A layer of soil about one-quarter inch thick was placed over the squares. Perfection seeds were then planted in the holes. In the first planting of the first three series (Table 10), it may be seen that 13 plants were killed, 11 of which yielded the wilt organism upon isolation. In the second planting of the same three series, however, 54 plants were killed and 45 yielded cultures of the wilt organism. The results of this experiment seem to indicate that, in general, some time is required for the fungus to become established in the soil.

The experiment by Snyder (14 and 15) also seems to indicate that some time is required for the fungus to become established in the soil after it is introduced.

CONTROL MEASURES

Once *Fusarium* wilt becomes established in a field, the outstanding method of control from a commercial standpoint is the use of resistant varieties (Plate IV). Walker (18) shows the degree of resistance and susceptibility of all commercially important varieties. According to Walker, a few of the most generally used canning and market garden varieties are as follows:

Susceptible	Resistant
Alaska (varies from 100% susceptible to 100% resistant)	Green Admiral
Horsford	Horal
Surprise	Improved Surprise
Laxtonian	Prince of Wales
Thomas Laxton	Senator
Winners	Roger's K
Perfection	Bruce
Advancer	First of All
Abundance	Dwarf Telephone
First on the Market	Alcross
Improved Stratagem	Giant Butter
	Stratagem

The use of seed from non-infested fields will no doubt delay the appearance of the disease in non-infested areas; once it appears, however, resistant varieties should be used.

Avoid as much as possible transfer of soil from infested to wilt-free fields.

Thoroughly clean all dust and debris from threshing machines after harvesting a wilt-infested field. This should be done even though the field may have been planted to resistant varieties.

Vines from infested fields should be destroyed. They may be used for silage, but direct feeding to animals may spread the disease although experimental tests fail to prove this point as yet.

From the standpoint of pea diseases in general, a rotation of from three to five years, where practicable, would certainly be expedient. The advice of your station plant pathologist should be sought on this point.

SUMMARY AND CONCLUSIONS

1. *Fusarium orthoceras* App. and Wr. var. *pisi* Linford is at the present time the most destructive disease of peas.
2. No host specialization of the fungus has been demonstrated, although observations seem to indicate that it exists.
3. Semesan seems to inhibit secondary invasions by other fungi although it apparently plays no part in checking infections by *Fusarium* wilt. Plants from Semesan-treated seed killed by wilt usually display more in detail and more accurately the symptoms of *Fusarium* wilt.
4. Temperature and certain fungi of the soil seem to be the most important single factors directly influencing symptoms.
5. Semesan treatment of seed is of no value in reducing wilt infection once the organism is established in a field. Semesan does, however, inhibit invasion by other fungi such as *Fusarium martii* var. *pisi*.
6. *Fusarium* wilt of peas is seed-borne. Preliminary tests failed to establish internal seed-carriage, although it is thought under some conditions to be possible. External seed-carriage is an important method of introduction of wilt into new fields.
7. The combine harvester plays an important role in local dissemination, as do also other farm implements, and is largely responsible for mixing of fungous spores, debris, and dirt with seeds.
8. The practice of feeding diseased vines to animals is not recommended although preliminary tests did not show that wilt spores remain viable after passage through their alimentary tracts.
9. Dissemination by birds is not considered of much importance, although it may be possible. Laboratory tests gave negative results for wilt spores after passage through the digestive tract of chickens. However, spores of *F. martii* var. *pisi* remained viable.

10. Dissemination of the wilt disease by wind may under some conditions be very important in a given vicinity.

11. It seems that at least one year is required after wilt is introduced into a wilt-free field to give killing. Experiments to determine the reason for this time requirement were not conclusive.

12. Use of resistant varieties appears to be the only means of control after the disease becomes established in the field. However, general sanitation, crop rotation, and seed sterilization are all very good practices for pea culture in general.

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